Committed Effective Dose Equivalent Calculation for Personnel Exposure to Airborne Radioactivity Produced by Main Injector Beam Loss

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A. Introduction

Airborne radioactivity is produced when particle beams interact with beam line components or enclosure air. The resulting cascade of secondary particles which travel through beam enclosures cause the air to become activated. The isotopes which form are short-lived positron emmitters and are sources of external radiation exposure, primarily annihilation photons. The common, most abundant isotopes found in measurements at Fermilab are C 11, N 13, Cl 38, Cl 39, and Ar 41.

Main Injector beam losses are expected to produce airborne radioactivity. The purpose of this note is to determine Committed Effective Dose Equivalent (CEDE) which could be received by personnel who access the MI beam enclosures when airborne radioactivity produced by activation of enclosure air is present.

B. Calculation

The CEDE resulting from personnel exposure to accelerator produced airborne radioactivity has been studied.[1] Airborne radioactivity is nominally measured by pumping ambient air from a beam enclosure through Tygon™ tubing to a one-gallon paint can. A GM tube installed in the paint can and connected to a typical electrometer detects radioactivity in the air. The output of the electrometer is sent to either the site-wide monitoring system known as MUX or to the controls system known as ACNET. The resulting measurement is a counting rate with units of counts per minute (cpm). Nominal background counting rates vary depending on the location of the paint can, but a resonably low counting rate of 20 to 50 cpm can be achieved with judicious placement of the paint can. The dynamic range of the paint can counting rate is approximately 0-50,000 cpm.

The unit of interest used to measure exposure by airborne radioactivity is the DAC or Derived Air Concentration. The radionuclides produced have been determined to be an immersion hazard rather than an inhalation hazard so the Derived Air Concentration for Submersion is the limiting DAC of interest. The DAC for Submersion is one two-thousandth of the time integral of the concentration of a radionuclide in air which over a working year would alone irradiate a person the annual limit of 5000 mrem. A person working in an area for one hour where the airborne radioactivity concentration is 1 DAC would receive a dose of 2.5 mrem. Values of DAC for submersion are given in 10 Code of Federal Regulation 835.

The DAC has been calculated for the anticipated loss points in the Main Injector.[2] The highest calculated instantaneous DAC for steady state operation at design beam intensity is 2.6 and is associated with the NUMI extraction area around MI 608. Personnel access is not possible when this level of airborne radioactivity is present because the beam enclosures are exclusion areas. Since the isotopes produced have relatively short half-lives, the DAC is quickly reduced when the proton beam is turned off. The CEDE is calculated by consideration of the time the radiation exposure begins after beam is turned off, the length of time of the exposure, and the isotope half lives.

An Excel spreadsheet has been created to permit rapid calculation of the CEDE under a wide variety of conditions.[1] An example of the spreadsheet is included as Figure 1. A "stack monitor input countrate" is the basic input parameter and was adjusted until a "DAC sum ratio" of 2.6 was found. Several interesting values are also calculated including "minutes until DAC ratio is below 0.10", "Total CEDE for access which begins immediately after beam off", and "Total CEDE for access which begins 20 minutes after beam off".

The "Total CEDE for access which begins immediately after beam off" is the maximum dose a person could receive if the person were able to enter the beam enclosure immediately after beam was turned off and stayed until after all radioactivity had decayed away with a starting instantaneous DAC of 2.6. A shorter access would result in a correspondingly lower dose. This is not a practical measure of potential dose because of the delays encountered in making an enclosure access. A more reasonable value "Total CEDE for access which begins 20 minutes after beam off" is a reasonable estimate of the dose a person may receive if the person enters the beam enclosure 20 minutes after beam is turned off and stays until after all radioactivity has decayed away.

MUX Quad/Address: NA   Enclosure: NUMI

Assume Deadtime 200 μs

Stack monitor input countrate: 10850

Deadtime corrected input stack monitor countrate: 11257.1

Isotope	1/2 life	Calibration Factor μCi/ml cpm	Enclosure Concentration μCi/ml	DAC'S	DAC RATIO
N-13	10	5.12E-10	5.76E-06	4.00E-06	1.44E+00
C-11	20	3.91E-10	4.40E-06	4.00E-06	1.10E+00
Cl-38	37	4.73E-12	5.32E-08	3.00E-06	1.77E-02
Cl-39	57	4.68E-12	5.27E-08	3.00E-06	1.76E-02
Ar-41	110	5.89E-12	6.63E-08	3.00E-06	2.21E-02

DAC RATIO SUM 2.60E+00

If DAC Ratio sum is greater than or equal to 0.10 then posting required, or procedurally prohibit access for a determined time period.

t = 79

	1.44	0.01
	1.10	0.07
	0.02	0.00
	0.02	0.01
	0.02	0.01
		0.10

Minutes until DAC ratio is below 0.10 79

0 minutes delay	Committed Effective Dose Equivalent (mrem) by Isotope	20 minutes delay	Committed Effective Dose Equivalent (mrem) by Isotope	Minutes Delay Until concentration is <10% DAC	Committed Effective Dose Equivalent (mrem) by Isotope
N-13	0.866	N-13	0.217	N-13	0.004
C-11	1.323	C-11	0.661	C-11	0.086
Cl-38	0.039	Cl-38	0.027	Cl-38	0.009
Cl-39	0.060	Cl-39	0.047	Cl-39	0.023
Ar-41	0.146	Ar-41	0.129	Ar-41	0.089
Total CEDE for access which begins immediately after beam off	2.435 mrem	Total CEDE for access which begins 20 minutes after beam off	1.081 mrem	Total CEDE for access which begins 79 minutes after beam off	0.210 mrem

Figure 1

C. Discussion

A very conservative upper limit on the estimated CEDE a person is likely to receive due to airborne radioactivity at the NUMI extraction region is 1.1 mrem. This is the region of highest potential air activation because of anticipated losses in the region. From reference 1, we may conclude that airborne radioactivity posting for the MI related enclosures will not be required since the eight hour, time-weighted average DAC will not exceed 2 mrem.

An additional, important mitigating factor not considered is dilution of the activated air volume. In reference 3, it is assumed that the concentration of airborne activity is created in stagnant air which is not mixing or moving. It is clear that substantial dilution of these concentrations can and will occur because of air circulation which is to be established in the MI tunnel.

The earliest potentially significant measure of airborne radioactivity is expected to be made in the MI 40 beam absorber enclosure. The GM tube/paint can style air monitor will be installed in the enclosure. Air in this enclosure is expected to be relatively stagnant while the beam enclosures are secure and personnel access is not possible.

The actual concentrations will be measured during commissioning and early operation of the regions of interest which include, MI40 beam absorber enclosure, MI52, MI30, and MI8. Measurements will also be made at the MI608 (NUMI extraction region) as the NUMI is commissioned.

D. Conclusion

Airborne radioactivity is an unlikely source of significant CEDE. Confirmatory airborne radioactivity measurements will be made during early commissioning and operation. If these measurements indicate that unanticipated higher levels of airborne radioactivity are produced, adjustments will be made to the entry control program and related Radiation Work Permits to ensure the requirements of the FRCM[3] are met.

No special bioassay program is required to measure CEDE due to airborne radioactivity produced from air activation when external dosimetery such as TLDs or film badges are worn by exposed individuals. Respiratory protection such as negative pressure, full face respirators or self-contained breathing apparatus would not serve to reduce exposure from these airborne radioisotopes.

References

[1] "Airborne Radioactivity in Accelerator Division, Radiation Physics Note 128", G. Lauten and T. Leveling, November1996

[2] "Ground Water, Airborne And Soil Activation From The Operation Of The MI40 Beam Absorber and Air Activation in the MI Enclosure", C M. Bhat and A. F. Leveling, MI Note-0219, July 1998

[3] Fermilab Radiological Control Manual.